BJ87

REPORT DOCUMENTATION PAGE	FORM APPROVED OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	11-10-96	Final Technical Report

4. TITLE AND SUBTITLE OF REPORT Scanning Tunneling Microscopy/Spectroscopy Studies of Nanostructures in GaAS	5. FUNDING NUMBERS
6. AUTHOR(S) M.G. Lagally	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Board of Regents University of Wisconsin-Madison 750 University Avenue Madison, WI 53706	8. PERFORMING ORGANIZATION REPORT NUMBER: N00014-90-J-1306-F
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research 800 North Quincy St. Arlington, VA 22217	10. SPONSORING/MONITORING AGENCY REPORT NUMBER: Office of Naval Research

11. SUPPLEMENTARY NOTES:

12a. DISTRIBUTION AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for public release; distribution unlimited.	Unclassified

13. ABSTRACT (Maximum 200 words)

19961226 099

DTIC QUALITY INSPECTED 4

14. SUBJECT TERMS	15. NUMBER OF PAGES: Seven
	16. PRICE CODE N.A.

17. SECURITY CLASSIFICATION OF REPORT:	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

Scanning Tunneling Microscopy/Spectroscopy Studies of Nanostructures in GaAs

Office of Naval Research
Grant No. N00014-90-J-1306
Final Report
November 10, 1996

Max G. Lagally
University of Wisconsin
Madison, WI 53706
Phone: 608-263-2078
FAX: 608-262-8353
email: Lagally@engr.wisc.edu

Introduction

This report briefly summarizes work completed on the above grant during the time period of December 1, 1989 to November 30, 1995. The grant has concentrated on Scanning Tunneling Microscopy/Spectroscopy (STM/STS) studies of atomic-scale structure and morphology in semiconductors. Earlier work on this grant, which was initiated in 1990, was extended the past three years (partially through the addition of AASERT funding) to include efforts to develop microcathodoluminescence (μ-CL), scanning tunneling luminescence (STL), and near-field scanning optical microscopy (NSOM) for investigating local optical properties of surfaces and small structures and relating these to morphological properties and structural defects.

Scanning Tunneling Luminescence

A significant accomplishment of this grant was the establishment of a scanning tunneling luminescence/microcathodoluminescence capability and using it to perform initial investigations on the wide-band-gap semiconductor GaN. STL shows great promise as a local probe of electronic structure and optical properties. The implementation of the technique is relatively straightforward when utilizing a working STM. In standard cathodoluminescence, a high-energy electron beam incident on a surface excites photons whose energy and intensity reflect electronic processes in the material. In STL/μCL, the STM tip is used as the tunable low-energy source of electrons. With a sensitive spectrometer and detector luminescence from very small regions of the sample can be detected. The system is directly compatible with existing STM chambers. We implemented STL through the addition of a lens on the STM that has a high collection efficiency. The light come out of the vacuum system into the detector. We are able to obtain simultaneous 2-dimensional topographic and luminescent images by scanning the tip and measuring the emitted light gated to the position of the point of carrier injection underneath the tip. The tunneling current provides the topographic image while the light provides the luminescent image.

The information obtained with STL is expected to extend our understanding of how dimensional constraints affect optical and electronic performance of compound semiconductors. For example, one should be able to probe the optical signals associated with steps, with different roughness of steps, with growth defects, and with rough surface morphology. Beyond this, one can probe shallow buried layers in multilayer films through injection of electrons. STL can also be used on cleaved multilayer films to probe the changes in electrical/optical properties as the composition changes from one layer to the next through a possibly intermixed or reacted zone at the interface.

The spatial resolution of the luminescence signal, one of the most important and interesting questions in the application of STL, depends on the sample temperature and the details of the current transport and distribution of the injected carriers. The focus of our initial work has been on mapping the spatial distribution of the signal on a nanoscopic scale. The very localized injected carriers will in any case allow for the majority of the luminescence signal to originate from a region much smaller than the conventional photo- and cathodoluminescence techniques. In our GaN studies, we found, surprisingly, that the spatial resolution was much better than expected: the existence of traps in the surface or near-surface region causes nonradiative recombination. In addition the mean free path of the injected carriers (holes for n-doped GaN) limits the spatial extent of the radiative recombination. A spatial resolution of the order of 1-2 nm was estimated.

Used in the cathodoluminescence mode (field emission from the tunneling tip when it is retracted), the instrument produces very bright luminescence from GaN. In this case electrons are injected. Apparently some of these higher-energy electrons reach the bulk to create electron-hole pairs that can then recombine to give off light. We have developed a model to explain the luminescence, as well as a noise-analysis procedure to demonstrate that the observed light is not simply noise. No obvious correlation with structural features such as steps was evident, suggesting that steps themselves do not act as recombination centers. More detailed analysis will be required to determine which defects correlate with the luminescence.

The STM/STL work on GaN has so far resulted in two publications in Appl. Phys. Letters, one published and one in press. A Ph.D. dissertation was written on this work (Brad Garni). An additional longer paper is in preparation. The APL is a photoelectron spectroscopy study of GaN surface cleaning procedures that points out that most work so far has been on contaminated surfaces. We performed this work to assess the quality of our own surfaces, which are of films grown in house by halide vapor phase epitaxy (HVPE) and by MOCVD. Films were grown by Tom Kuech.

Separately, a near-field scanning optical microscopy facility was acquired. Because it does not operate in UHV, it has been used primarily for other purposes, as we have concentrated on STL in vacuum on clean surfaces.

STM Studies of Surface Defects on Semiconductors

The second (and somewhat older) area of research involved the investigation of defects on semiconductor surfaces using STM/STS. The work on GaN described above evolved from this earlier work. Efforts concentrated on two areas, point defects in GaP surfaces and the lattice-stress-induced formation of defects in Ge/Si(001) and GeSi/Si(001). Our contribution to the former work, which led to two PRLs and three other papers, was primarily theoretical and interpretational, as the measurements were done In Germany by a postdoc who subsequently joined us as a Humboldt Fellow. On the basis of our experience with STM of defects on semiconductors, we were able to provide what may possibly be a breakthrough interpretation of the structural and electronic nature of vacancies on III-V surfaces.

Our SiGe work, although considered "early", continues now under separate funding. The "big picture" here is observing the influence of lattice strain for heteroepitaxial films on the evolution of surface structure, in particular defect structure such as dimer vacancy rows, islanding, and the transition to 3D growth; on kinetics of transport at the surface; and on step and kink energetics. A series of three PRLs presented a complete look at the effect of monolayer adsorption of Ge on the Si(001) surface structure and energetics. In the future, this work will consider the use of compliant substrates to establish whether surface phenomena and transport change if the substrate is able to absorb a larger part of the strain because it is very thin. The hope is to be able understand how strain can be "diverted" so that an additional parameter can be controlled in the growth of heteroepitaxial films. This concept will especially be applied for SiC and GaN growth on Si(001) in a project funded separately by ONR.

Publications

Listed below are the publications resulting from the research of the last three years. Several additional ones, in particular on GaN, and in preparation.

"An Atomic-Level View of Kinetic and Thermodynamic Influences in the Growth of Thin Films", M. G. Lagally, Jpn. J. Appl. Phys. 32, 1493 (1993) (invited).

"Scanning-Tunneling-Microscope Tip-Induced Migration of Vacancies on GaP(110)", Ph. Ebert, M. G. Lagally, and K. Urban, Phys. Rev. Letters 70, 1437 (1993).

"Variable-Temperature STM Measurements of Step Kinetics on Si(001)", N. Kitamura, B. S. Swartzentruber, M. G. Lagally, and M. B. Webb, Phys. Rev. Rapid Comm. B48, 5704 (1993).

"Step and Kink Energetics on GaAs(001)", E. J. Heller, Z. Y. Zhang, and M. G. Lagally, Phys. Rev. Letters 71, 743 (1993).

"Real-Time Observations of Vacancy Diffusion on Si(001)-(2x1) by Scanning Tunneling Microscopy", N. Kitamura, M. G. Lagally, and M. B. Webb, Phys. Rev. Letters 71, 2082 (1993).

"Roughening of Steps During Homoepitaxial Growth on Si(001)", F. Wu, S. G. Jaloviar, D. E. Savage, and M. G. Lagally, Phys. Rev. Letters 71, 4190 (1993).

"Vacancy-Vacancy Interaction on Ge-covered Si(001)", X. Chen, Z.Y. Zhang, and M. G. Lagally, Phys. Rev. Letters 73, 850 (1994).

"Atomic Point Defects on III-P(110) Semiconductor Surfaces Observed by STM", Ph. Ebert, M. G. Lagally, and K. Urban, in Formation of Semiconductor Interfaces (Proceedings of the 4th ICFSI), eds. B. Lengeler, H. Lüth, W. Mönch, and J. Pollmann, World Scientific, Singapore (1994).

"Reversal of Step Roughness on Ge-Covered Vicinal Si(001)", F. Wu, X. Chen, Z. Y. Zhang, and M. G. Lagally, Phys. Rev. Letters 74, 574 (1995).

"Formation of Anion Vacancies by Langmuir Evaporation from InP and GaAs(110) Surfaces at Low Temperatures", Ph. Ebert, M. Heinrich, M. Simon, K. Urban, and M. G. Lagally, Phys Rev. B51, 9696 (1995).

"Temperature Dependent Vacancy Concentrations on InP(110) Surfaces", M. Heinrich, Ph. Ebert, M. Simon, K. Urban, and M. G. Lagally, J. Vac. Sci. Technol. A15, 1714 (1995).

"Ge-Induced Reversal of Surface Stress Anisotropy on Si (001)", Fang Wu and M. G. Lagally, Phys. Rev. Letters 75, 2534 (1995).

"Scanning Tunneling Microscopy and Tunneling Luminescence of the Surface of GaN Films Grown by Vapor Phase Epitaxy", B. Garni, Jian Ma, N. Perkins, Jutong Liu, T. F. Kuech, and M.G. Lagally, Appl. Phys. Letters 68, 1380 (1996).

"Direct Determination of the Interaction Between Vacancies on InP(110) Surfaces", Ph. Ebert, Xun Chen, M. Heinrich, M. Simon, K. Urban, and M.G. Lagally, Phys. Rev. Letters 76, 2089 (1996).

"Kinetics and Dynamics of Defects on Si(001)", Zhenyu Zhang, Fang Wu, and M.G. Lagally, Surface Review and Letters, (Sept. 1996, in press), (invited review).

"Photoemission Spectroscopy Studies of the Surface of GaN Films Grown by Vapor Phase Epitaxy", Jian Ma, B. Garni, N. Perkins, W. L. O'Brien, T. F. Kuech, and M. G. Lagally, Appl. Phys. Letters (submitted).

Awards

During this grant period, the Principal Investigator received several awards. In considerable measure based on the work performed under this grant. The awards were

1. David Adler Lectureship Award of the American Physical Society

2. MRS Medal of the Materials Research Society

3. Davisson-Germer Prize of the American Physical Society

4. Outstanding Science Alumnus Award, Pennsylvania State University